



USING GLOBAL POSITIONING SYSTEM TECHNOLOGY FOR WATERSHED MAPPING IN CASPAR CREEK

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Surveying and mapping work has been an essential and time consuming part of the Caspar Watershed study during the North Fork phase. The cumulative effects study and several other studies being done in this phase require accurate mapping and periodic map updating of watershed features and disturbances. Initially, stream channels were surveyed using conventional theodolite equipment and later surveys were done with electronic distance meter (EDM) surveying equipment. The Pacific Southwest Forest and Range Experiment Station (PSW) Redwood Sciences Lab initiated the project with the objective of evaluating the use of global positioning system technology (GPS) as an alternative to EDM surveying under varying conditions using both ground and aerial surveying methods.

What is GPS?

As one might imagine from the system name, this positioning system is based on satellite technology which, when the system is completed in 1992-93, will have 24 satellites in orbit. The system will allow users with system receivers 24-hour

navigational and position coverage at any point on the earth. The current system of satellites orbit 11,000 miles above the earth, each one circling the globe twice a day. The GPS was developed by the Department of Defense for military application and was the key for ground navigation during the Gulf War. Congress authorized ten billion dollars for system development with the allowance that civilian application would be possible. Currently, about 75 percent of the satellites are in orbit. This restricts optimal satellite access to certain hours or "windows" each day. These windows are present when signals from four or more satellites can be received by the ground unit. A minimum of four satellite signals are required for the ground receiver to determine a precise "3D fix" for a position. The satellite windows can be calculated for specified time intervals any day of the year given the receiver's location.

The method used by the ground receiver to determine precise location requires timing accuracy on the order of a billionth of a second as well as sophisticated software. The system receivers receive orbital correction and timing data from the satellite in addition to having the satellite positions programmed in

memory. The timing accuracy is achieved by using an extremely expensive atomic clock on the satellite. It is synchronized with a moderately precise quartz clock in the receiver using a complicated digital code which repeats the same sequence every millisecond. This code is generated by the satellite and ground receiver at exactly the same time. By comparing the incoming code signals against the internally generated code, the receiver can determine when the signal left the satellite and thus compute the distance. Given the distance to each satellite and knowing each satellite's position, the receiver can solve for its own position.

Although three satellites can be used to obtain a fix, four are required for a corrected three dimensional fix. This is due to the timing error [offset] of the less precise ground based receiver clock. When the receiver calculates that there is not a perfect intersection of the solution of four bearings and distances, it will start making adjustments until a perfect fit is attained. The GPS receiver will automatically pick the optimal combination and number of satellites when computing a fix. For a more detailed explanation we recommend you obtain a

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Figure 1. The author demonstrates a technique for improving GPS signal reception when mapping understory features.

copy of a publication from Trimble Navigation called "GPS-A Guide to the Next Utility." The company can be reached by calling 408-730-2900.

Several types of GPS receivers are available commercially with prices starting at several thousand dollars and going up to twenty thousand and more for land surveying units. The least expensive units are of the sequencing, single channel type. More costly types range from the fast multiplexing single channel and two channel units to continuous multichannel receivers that will simultaneously receive and process multiple satellite signals.

The Caspar Watershed Mapping Project Application

The multichannel receivers used on this project have the capability to receive signals and calculate a fix from up to six satellites simultaneously about once per second. They serve as combination

receivers and data loggers so all fixes are logged into a data file in memory which can later be transferred to other computers for further processing.

The US Forest Service has purchased many of these units and Mike Jablonski, a forester on the Lassen National Forest, was able to share his expertise and equipment in making this project possible. Mike had previously used helicopter GPS surveying for wildfire mapping work. His equipment was manufactured by Trimble Navigation Ltd. of Sunnyvale who also became involved in this project. They were

interested in developing new GPS applications and testing their equipment under different field conditions.

For the helicopter mapping phase of the project, Mike brought a metal antenna mounting plate with suction cups on the underside which is tied down to the tailboom of the CDF helicopter (Figure 2). The small cubical shaped antenna is screwed onto the mounting plate so there is minimal wind resistance and virtually no danger of rotor blade obstruction. Antenna wire is led up to the passenger compartment of the helicopter for connection to the receivers and secured to the side of the ship with tape.

Chuck Gilbert, the representative from Trimble, brought a new model receiver/datalogger to try on the project. This receiver can accept feature information [attribute] for a series of coordinate fixes using a bar code technique. Depending on project needs, a bar code template is made and each code is then

pre-identified with some attribute being mapped. When starting a data set on a particular feature, a light pen is run over the appropriate bar code and the attribute is automatically entered into the data logger for the following set of fixes. This is a powerful tool, especially for rapidly mapping a number of specific features as is needed in aerial mapping applications.

The week long project took place in July as calculations showed that four windows per day were practical to use. One occurred in the early morning, another around noon, the third near mid-afternoon and the last was in the late afternoon. Windows ranged in duration from 45 minutes to 2 hours. These windows were defined by having four or more satellites at least 15 degrees above the horizon. In mountainous terrain it is critical to have satellites with sufficient elevation above the horizon to achieve adequate reception.

One technique used on the project is called differential surveying. This technique increases the single receiver accuracy of plus or minus 15 meters to 3-5 meters or less. A base station receiver is set up in the local area and logs positional data simultaneously with the mobile unit. This procedure is needed because of the changes in air water vapor content, geometric dilution of satellite angles and ionization in the upper atmosphere. To implement this technique we set up one base station receiver at Soldier Rock National Geodetic Control benchmark on the Georgia Pacific mill property in Fort Bragg. This particular reference point was chosen because it had no viewing obstructions and is a known location which is tied into a national grid system.

Three types of mapping techniques were used on this project. Two ground based techniques were used first. Several sections of stream channel and one clearcut unit boundary were mapped by one person walking while carrying a receiver/antenna unit on a backpack frame (Figure 1). Many of the log haul roads were mapped using the GPS unit mounted on a vehicle. The roads were driven while logging data, noting the landings and

spur road locations. The third method used a helicopter for aerial mapping of the same features plus others which we did not have time to visit on the ground.

We found that for current applications of the system in this type of terrain, ground based mapping had limited use. This was especially true for the walking application where the crew was doing mostly channel mapping. The combination of heavy overhead canopy and restricted viewing angles due to narrow, deep canyons drastically reduced satellite reception in these stream channel locations, allowing few 3D fixes. This effect was less of a problem when driving and locating ridgetop features but a smaller portion of the mapping work was needed at these locations.

Pre-planning of mapping times is critical to achieve any degree of success due to current limited windows for satellite reception. There can be significant mapping downtime between window periods. Depending on project location, considerable time can be spent in travel. Our project location was one-half hour from the office and some mapping units were twenty minutes hiking time from the nearest trailhead. In our application, mapping crews used the in-between periods to drive back to the office, download data to the computer and process the data files. Mike would pick up the stationary differential receiver and bring it to the office to download that data and recharge the battery as needed. The receiver would then be re-installed at the location prior to the next mapping period.

The aerial mapping application using a helicopter however proved to be an extremely effective and swift method for mapping in this terrain. The California Department of Forestry and Fire Control (CDF) through the Mendocino Ranger Unit made a substantial contribution to the project by lending their fire control helicopter. Copter 101 from the Howard Forest Helitack base, a military version of the Bell 204, flew three missions to acquire the data. On each flight, five people flew with the pilot and forward observer. Two of the project staff had



Figure 2. Mounting the GPS antenna on the helicopter.

receivers, one coordinated the start and end of a certain pass for one watershed feature while another recorded other relevant information about each data set for later clarification.

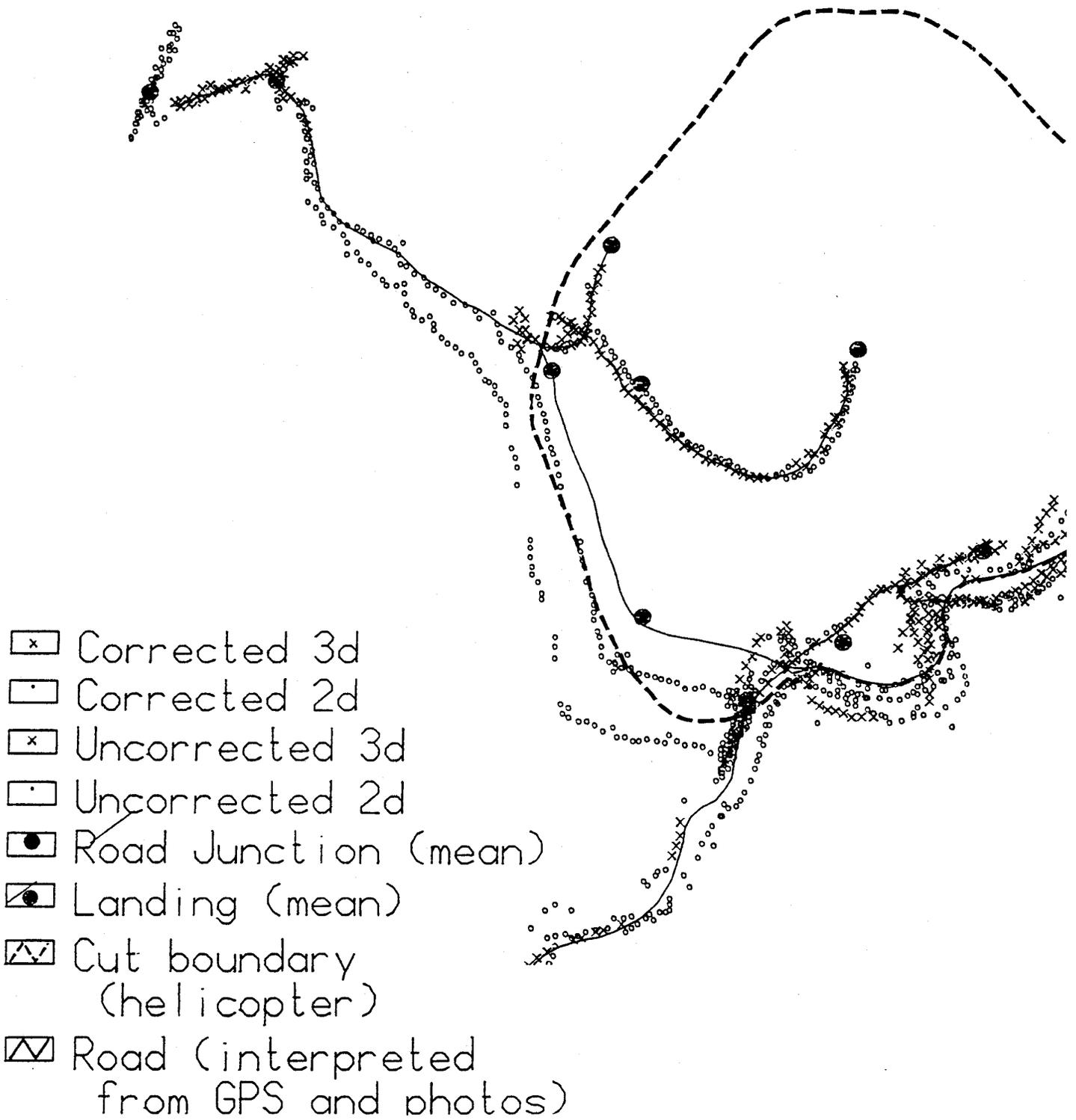
The first flight was aborted because of an extensive fog layer. The second and third flights were very successful with all of the designated clearcut units boundaries, roads and certain other features being flown and surveyed. Both flights demonstrated the feasibility of using a

helicopter for aerial based mapping with GPS. The pilot was able to follow the varying lines of harvest unit boundaries, using one side of the landing gear as a reference point. Once a mapping run commenced the pilot would fly approximately 100 feet or less above the tree tops, often being level with upslope trees (Figure 3). At harvest unit corners, the pilot was able to rotate the helicopter on a stationary point to keep the antenna on line with the cut boundary. Each



Figure 3. The pilot traces the unit boundaries and watershed features while the GPS receiver interprets signals, calculates coordinates, and records data.

Caspar Creek "K" Cut



ut Unit



Figure 4. Map generated by computer and plotter from GPS data. Original map uses color to indicate differences between corrected and uncorrected points.

flight lasted about one hour and covered approximately ten miles of unit boundaries plus several miles of road (Figure 5).

Based on our experience, it would seem possible to accomplish the complete aerial mapping operation in a single flight. Multiple flights were needed for this application due to weather and equipment difficulties. Minimum staffing would consist of an experienced pilot and an operator for the GPS unit.

Data Processing and Output

All of the data from the mapping receivers and stationary differential receiver were periodically brought into the office at Fort Bragg and downloaded onto a microcomputer which had been loaded with Trimble's data processing software. Chuck Gilbert did some of the initial data processing but Jack Lewis from PSW is in charge of processing all the data and integrating it into their geographic information system (GIS) to produce a final map (Figure 4).

The first part of the data processing involves using the differential survey technique by correcting the data acquired from the mobile GPS receiver. The data sets from the stationary receiver and mobile receiver are input and Trimble's "PFINDER program" corrects the mobile receiver data file.

The files had a mixture of 2D and 3D fixes. The ultimate inclusion of the 2D fixes depended on the number, distribution and frequency of the 2D points in relation to the 3D fixes in a data set. In addition, there were numerous passes on many of the features in the watershed. Some roads had both vehicle and helicopter passes and one unit boundary was both walked and flown. These duplicate data sets have been evaluated for the quality of the data for inclusion in the mapping work.

On fixed positions, the files were filtered to extract the 3D coordinates and obtain a mean elevation for the set of points. This elevation was then used to adjust the intermixed 2D points in the data set. Statistics were then generated on each



Figure 5. An experienced pilot is needed to accurately fly the unit boundaries and roads.

UTM coordinates and input into ARC-INFO. The road information for each type of data was plotted in a unique color so that the discrepancies between the four types of data could be easily compared. Where gaps in the 3D corrected data occurred, the next best data was used and adjusted to fill in the hole. If landings and roads did not meet, the road location was adjusted to intersect the landing. Discrepancies between the helicopter data and ground data for the same features was resolved by using the helicopter data which had much more 3D data than the ground based data. Using

data set to document the standard deviation on the latitude and longitude. The data set with the least variability was usually selected to represent that particular feature. This coordinate pair is then fed into the ARC-INFO GIS system and plotted on the base map. The current source for the base map for the North Fork of Caspar Creek is the Comptche SW 7.5 minute preliminary quadrangle sheet which were used to develop the published 15 minute USGS quad maps.

Non-fixed attributes (like road traverses) were handled differently in the processing phase. Four types of data were developed from the raw data. These data consisted of 3D and 2D fixes both differentially corrected and uncorrected. Unfortunately the base station had some down time due to power loss, memory limitations, and data files that were lost in the transfer process to the computer. The corrected data was converted to

large scale (1/6000) aerial photos taken in 1987 will help resolve discrepancies in the final positioning and geometry of all the features.

Initial Project Evaluation

This technology is already being widely used in many different resource applications and shows great promise in this application. With more optimal satellite combinations available in the future, GPS mapping should become more cost effective and signal reception improved in currently poor reception locations.

The watershed features surveyed using this GPS technology are now not only accurately located in relation to other objects in the watershed, but also to a regional and global frame of reference. GPS has given the researcher and resources manager a powerful new tool natural resources field.